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Chapter 1

Reaching Out

Earth. A beautiful word, Earth. It summons visions of mountains, oceans, blue skies and clouds, wind and rain, prairies and plowed fields, life. Our small planet is utterly central to us. Whatever happens almost anywhere on it affects our lives. The only body of comparable importance is the Sun, which provides heat, light, nearly all of our energy. Without either Sun or Earth, we obviously could never have come to be. We are the sons and daughters of both.

The nighttime sky reveals a different face. The blue cover is replaced by a black one alight with stars, shifting planets, the Moon, and occasional comets and meteors. Though foundations of art, music, philosophy, the residents of night seem otherwise to have little effect. Looking outward from our home, we feel suitably isolated. We might spend a lifetime watching the heavens, yet nothing much, if anything at all, seems to happen there that has anything to do with our lives.

But that is only because we do not look closely enough, or live long enough, to witness the whole story. While some influences have long been known (lunar tides, for example), only over the past century or so have we learned that we are profoundly affected not just by the Sun and Moon, but by practically everything that happens "out there." We are not just the children of Earth and Sun, but of the starry Universe.

Among the most amazing discoveries of modern astronomy is that even our day-to-day affairs are in fact subject to the vagaries of distant planets and stars. No astrology here: just good science that has uncovered the true planetary and stellar influences, which are far grander than any "magical" ones could ever be. Over the nine chapters that follow, they will be revealed as we reach out from our home ever deeper into the heart of outer space to experience not isolation, but a grand synergy in which everything influences everything else. But first we need a summary of what is actually out there, so as to provide a context for what is to come.

Stars

Stars surround us, eight to ten thousand of them visible to the eye alone. A handful brilliantly punctuate the darkness, while the fainter ones overwhelm our vision with their sheer numbers. There is no record of discovery. Stars have been seen, admired, loved, feared, studied, romanticized, since humans first looked upward. Long shrouded in mystery, they were believed by our ancestors to have been placed by the gods into patterns—constellations—to tell stories, to instruct, to commemorate, to note the passage of time. To the north roam the two celestial Bears, Ursa Major and Minor; to the south stalks Orion the Hunter, accompanied by his two canine companions, Canis Major and Minor. Farther south sails the ship of the Argonauts, while girdling the sky in a great circle are the twelve ancient animalistic figures of the Zodiac, which cradle the Sun (Libra once being the Scorpion's claws).

All cultures recognized such stellar patterns, "ours" coming down to us from Babylonia and before. Ultimately, forty-eight of them were passed to us through the hands of the ancient Greeks and Arabs. Thousands of years after their invention, we still celebrate them from our own backyards, allowing our forebears to reach out to touch us across the ages. These ancient constellations are supplemented by new ones culled from the interests of our own more modern times (a furnace, sextant, microscope), giving us eighty-eight of all sizes and shapes displayed across the northern and southern celestial hemispheres, to which are added dozens of informal configurations.

Telescopes reveal an uncountable population of stars: millions, billions. In reality they are other suns of all colors, kinds, forms, sizes, and ages. Self-luminous, they send us signals of light from

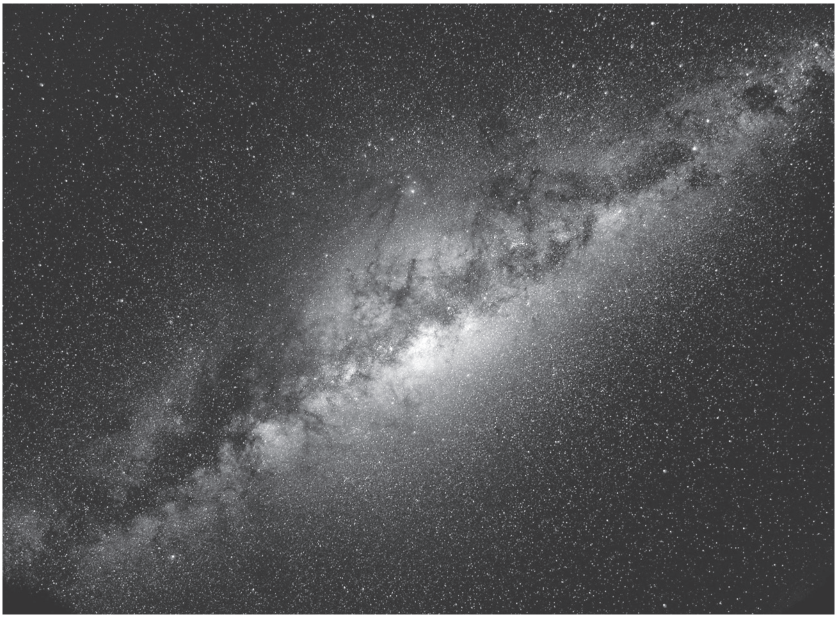

Figure 1.1. The bright half of the Milky Way, the combined light of the stars in the disk of our Galaxy, spills across the sky from north at left to south at right. The complex dark bands are made of thick clouds of interstellar dust that are the birthplaces of stars. The Southern Cross lies at the upper right-hand corner. The left-hand star of the pair just down and to the left of the Cross is Alpha Centauri, the closest star to Earth, four light-years away. Antares in Scorpius is the bright star just above center. Courtesy of Serge Brunier.

distances measured in impossibly long units. The Sun, 150 million kilometers (nearly 100 million miles) away, provides a fundamental measure. One hundred times the diameter of Earth, our star holds more than 300,000 times Earth's mass. Running on nuclear power (the conversion of hydrogen into helium), one second's worth of its radiation could provide all the energy used on Earth for the next million years. Other stars range in size from that of a small city to the orbits of the giant planets; in mass from a few percent that of the Sun to over 100 times solar; in age from newly born to nearly the age of the Universe itself. Once created, they live mostly quiet lives until their internal fuel runs out, at which point they enter desperate straits, first swelling to gigantic proportions before dying as tiny, worn-out cinders. Along the way they produce some of the most beautiful sights of nature. A tiny few even explode, whence in their nuclear fury they manufacture most of the chemical elements of which we are made.

Planets

Against the distant stellar background lie the planets of our Solar System. All but the farthest of them appear to outshine the stars, which are hundreds of thousands, millions, of times farther away. As the planets orbit the Sun, each on its own path, each taking its own time, their movements against the Zodiac long ago captured the imagination, so much so that in ancient times they were related to gods. There flies fleet Mercury the Messenger. Now you see him in evening twilight, but look quickly before he flits into morning. Visit next with peaceful Venus, the classic brilliant evening or morning star, Aphrodite, goddess of love and beauty, whose glow can be seen in full daylight and can cast eerie shadows at night. Jumping over Earth, find reddish Mars, the leering god of war, half again farther from the Sun than we. Then walk with stately Jupiter, king Zeus himself. Five times Earth's distance from the Sun, he spends a year visiting each of the dozen zodiacal figures, every 20 years passing his doubly distant, slower, fainter, defeated father, Saturn. Perhaps from their zodiacal homes the gods can tell us the meanings of our lives, can reveal our fates, the fortune-telling art of astrology not splitting off from astronomy until we began to see the planets for what they actually are: other "earths" cast into a variety of forms. To these, add the two discovered in modern times. Another near-doubling of distance gets us to Uranus, named after the embodiment of the heavens themselves. Half again farther out gets us to Neptune, named for the god of the Sea. Discovered only in 1846, it takes a century and a half to make a full loop of the Sun.

Nearby, orbiting our Earth and brighter still, is our small sister planet, the Moon, which constantly changes shape as she makes her monthly rounds. Not only can we see the Moon resolved as a disk with the naked eye, it's so close that we can even see dark features on its surface, of which the old-timers made fanciful figures, but which we now know are ancient lava flows closely related to a battered, beaten, punctured, cratered surface. In between is the leftover debris of the formation of our planetary system, made of asteroids that flock between Mars and Jupiter and of the icy comets that thrive mostly beyond Neptune and that are related to the "last planet," tiny Pluto. While rare among the small planets of the inner Solar System, dozens of moons flock around the giant planets from Jupiter on out.

While the interactions between the stars, Sun, Moon, and planets with our Earth are deep and complex, our first appreciation of them all is still through the light they send us. Stars and the Sun make their own radiant energy, while the planets and the Moon shine by reflection—as does the Earth. However it is produced, our first thought is always to look to the

Light.

Light: our human window to our surroundings and to the sky. Nothing is so fast! Indeed, nothing *can* be so fast. Turn on an imaginary flashlight and three-billionths of a second later the radiant beam is a meter away; in a second and a half it has passed the Moon (384,000 kilometers, 239,000 miles), in eight minutes the Sun (150 or 93 million). In three hours it begins to exit the planetary system, zipping by Neptune at 300,000 kilometers (186,000 miles) per second, then an hour later past Pluto's path. Such a beam would next go on a long lonely ride for at least *four years* before it would encounter another star, one then said to be four "light-years" away. And it would fly for thousands of years before it passed the last star visible without a telescope.

Light: our human window to the past. Reverse the flow and let natural starlight fall toward you. Because of the time needed for light to travel, we see the most distant stars as they were thousands of years ago, Pluto as it was four hours ago. Sunlight is eight minutes old. Even your friends appear as they were a few billionths of a second ago. The "present" is as we see it with our own eyes. Everyone thus has a different view of reality.

Light: strange stuff. As a flow of alternating electric and magnetic fields (the two forever linked together, each causing the other), no one has ever actually "seen" light itself; we instead sense the effect it has on our eyes. A major means of moving energy from one place in the Universe to another, light behaves in part like a continuous wave, much like the wave patterns that glide across the sea. The shorter the distance between wave crests (the "wavelength"), the more waves hit you per second, and the more energy a wave train can carry. But light also acts like a pack of speeding bullets, as particles, "photons" that hurdle along from source of the light to the eye. Light's strangeness is that it behaves as waves and particles *at the same time*, a concept that renders our best intuitive imaginations powerless.

Another strangeness (to us, not to Nature) is that photons have no mass, no "weight"; they are the only particles known that do not. In his relativity theory, Einstein showed us that mass (M) and energy (E) are related through perhaps the most famous equation ever written, $E = Mc^2$, where c is the velocity of light. While the speed of light alone is huge, squaring it (multiplying it by itself) makes the number vastly larger, such that a tiny amount of mass can be turned into a startling amount of energy—which is the key to nuclear and stellar power.

Energy, which comes in many forms, can in its crudest sense be thought of as the ability of a body to accelerate or to give heat to another. With more mass and higher velocity, a speeding car obviously has more energy than a running human. Einstein also then revealed that as the velocity (hence energy) of a particle increases ("relative" to us), so does its perceived mass. At light-speed a particle's mass would become infinite, which is impossible. However, since photons have no mass to begin with, only they are allowed to run at the limit. Anything with mass is confined to less than light-speed.

For all its richness, our personal window on the Universe is terribly small within a stunning range of wavelengths, within the "electromagnetic spectrum." With our eyes, we see those waves that fall between 0.00004 and 0.00008 of a centimeter (where, not so oddly, the Sun and stars generally emit the most of their energy). We sense the different visible wavelengths as different colors. At the long end, we see red, at the short end violet, with orange, yellow, green, blue, and their hundreds of overlapping shades in between.

Outside of this visual band, our eyes cannot register wave-photons, no matter how powerful or how many there may be. Longer than the visual wavelength limit—up to about a millimeter—lies the "infrared." Longer waves, into kilometer-wavelengths toward an unknown end, we loosely call "radio." Conceptually, however, all are the same. All are still "light" that carries energy, all running (in the vacuum) at the "speed of light." Long waves mean low energy, such that (unless at high intensity or at specific wavelengths such as those found bouncing within a microwave oven) they pose little danger to us or other living things.

Shorter than the visual limit, more violet than violet, is the *ultra*violet. If less than a percent or so of the wavelength of visual light, the waves are called X-rays. Another factor of 100 smaller, we enter the domain of "gamma rays." Short waves carry higher energies, resulting in increasingly higher danger. Ultraviolet light from the Sun will burn your skin, while X-rays (unless used properly for their medical benefit) are downright dangerous; gamma rays can be lethal. Fortunately, the latter two and most of the ultraviolet realm are blocked by the Earth's protecting atmosphere.

Together, stars, the dusty gases in the space between the stars, and related cosmic objects, emit across this entire wavelength array. Among the great triumphs of twentieth-century astronomy was the opening of the electromagnetic spectrum to our view via a startling array of new technologies. The expansion of our vision began in the 1930s with radio astronomy, and ended with gamma rays and X-rays observed from satellites orbiting in the depths of space above the surrounding atmosphere.

The visual spectrum from violet to red is but one octave on an imaginary electromagnetic piano with a keyboard hundreds of kilometers long. All of it is available for inspection, allowing us to explore the depths of the system of stars in which we live, of our Galaxy.

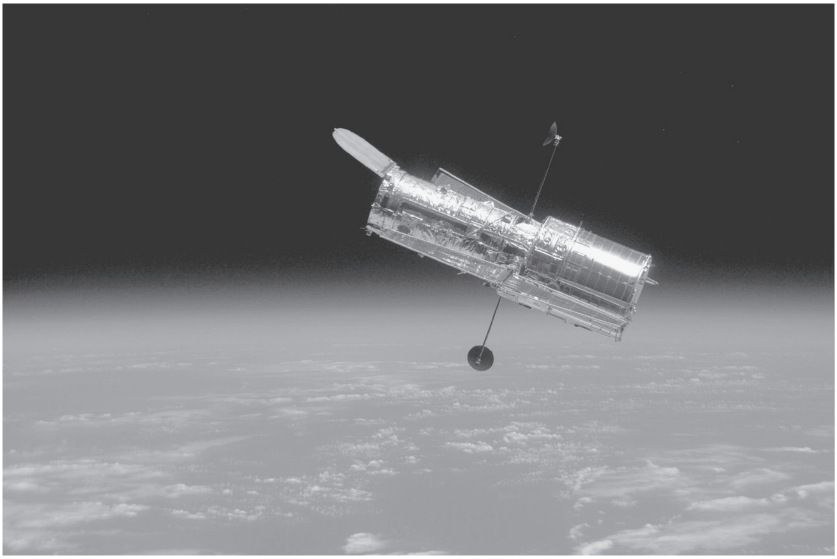

Figure 1.2. The Hubble Space Telescope orbits against the background of Earth and its clouds. Launched in 1990, the HST epitomizes the dozens of space observatories that can "see" with exquisite detail across the electromagnetic spectrum. NASA.

The Milky Way

Imagine a scene not from Earth's surface, where our planet creates a horizon that cuts out half the sky, but from deep space outside the Solar System, where you can get a full view of the celestial sphere that seems to surround us, and thus of all the stars that make themselves known to the unaided eye. No longer twinkling from the disturbing effects of Earth's atmosphere, they are point-like jewels set on a black cosmic cloth. Splitting the heavens in two is a luminous, highly irregular band of light—the Milky Way—made of the combined light of billions of stars that are individually invisible. Toward the zodiacal constellation of Sagittarius (the Archer), the Milky Way is bright and broad, while in the opposite direction, toward Taurus (the Bull) and Auriga (the Charioteer), it appears faint and indistinct.

The Milky Way, the subject of countless tales and poems, is the visual manifestation of our Galaxy, our own real home, a collection of over 200 billion stars of which our Sun is just one. Most of the Galaxy's stars are arranged in a thin disk that is filled in the middle with an even thinner layer of free gas and dust. The system is so big that it would take a light ray more than 100,000 years to make the journey from one side to the other. There really is no definable visual edge: our stellar system just gradually fades away. We, set within the disk, see it around our heads as the storied band of light, while the layer of dusty gas clouds (from which new stars continuously condense) divides the band in two, like the filling of a cake. Though located well within the disk, we are far from the center, hence there is a dramatic variation in brightness as we gaze around the Milky circle. Surrounding the whole affair is a vast and encompassing, though sparsely populated, spherical halo.

Within the disk some stars gang together into clusters that tell of common birth. Among the most beloved of celestial sights are the Pleiades—the Seven Sisters—and their mythological half-sisters, the Hyades, both in residence in Taurus. Under the curve of the Larger Bear's Big Dipper flows another, Coma Berenices (Berenices's Hair), while off in Cancer's direction the Beehive buzzes with its delightful swarm. The telescope shows such clusters to contain hundreds, even thousands, of members, while in the Galactic halo are a handful of gigantic clusters that can contain millions of stars, some of their fuzzy glows also visible to the naked eye. Even if—perhaps like the Sun—stars have drifted away from their birthmates, they are still companionable, a goodly fraction of them double, triple, quadruple, even more, in a hierarchy of gravity-bound neighbors.

To keep the Galaxy from collapsing on itself through the combined gravity of its stars, the stars must be circulating—orbiting—causing our Galaxy to rotate, though not as a solid body. Instead, the inner portion rotates in much less time than the outer regions. Our own Sun takes 250 million years to make a full circuit. All the stars around us have their own unique paths that depend on

Figure 1.3. No, not the Dipper, but the Pleiades (Seven Sisters) star cluster that graces the constellation Taurus. While only six stars are visible to the ordinary eye, the cluster—430 light-years away—contains hundreds of fainter ones. Bound together by gravity, the Pleiades is but one of thousands of clusters, some of which contain millions of stars. The cluster's hottest and brightest stars illuminate a thin dusty gas cloud through which the cluster is now passing. Courtesy of Mark Killion.

the gravities they feel, such that all seem to drift past us or we past them. Over the next thousands of millennia, the constellations will slowly change their shapes until they become unrecognizable to our current eyes, as the Sun and its Solar System travel on a slow but steady journey to the Galaxy's other side. By then, none of the stars we now see will be visible, but will instead be replaced by others that we in our present era cannot see at all. Gravitational disturbances and rotation also help spread out the stars into a huge pinwheel of graceful "spiral arms," rendering ours a classic "spiral galaxy."

And if this system, our Galaxy, seems almost overwhelming, there is more: we are not alone.

Figure 1.4. Want to see what our Galaxy might look like? The Andromeda galaxy is (like our own) a flat disk over 100,000 light-years across that lies some 2.5 million light-years away. New hot blue stars crowd outer spiral arms, while ancient reddish stars flock toward the center. Below center and to the upper right are a pair of small companion elliptical galaxies. NOAO/AURA/NSF/WIYN.

Galaxies

Off in vaster distances lie other galaxies. Four are visible to the naked eye. From the Earth's southern hemisphere you can easily spot a pair of small ones some 180,000 light-years away, the two irregularly shaped Magellanic Clouds, which orbit our larger Galaxy as satellites. In northern autumn evenings look to the constellation Andromeda to find a small cottony patch nicely visible without the telescope. The most distant thing the unaided human eye can see, the Andromeda Galaxy lies two and a half million light-years off. Another spiral galaxy even grander than our own, it may contain twice as many stars. Nearby, in the neighboring constellation of Triangulum (the eponymous Triangle), and at a similar distance, lies a much smaller spiral available only to younger eyes viewing from extremely dark sites.

Huge as these distances seem, they are just a small step into the cosmos. Ours, these four galaxies, plus another few dozen small scrappy ones are tied together through their own mutual gravities into a poorish cluster called simply "The Local Group." Farther out, 150 million light-years away, is a much grander cluster. Nearly filling the large zodiacal constellation Virgo, the Virgo Cluster contains thousands of galaxies, the biggest an ellipsoidal, nonspiral structure more than ten times as massive as our own Milky Way system.

The farther away we look, into distances measured in billions of light-years, the more we see—individual galaxies plus hundreds, thousands of their clusters, each containing thousands of individual members. The number of galaxies now seems almost infinite, one piling on top of the other, more galaxies than there are stars within the Milky Way. If we could add up all we could potentially see in our best telescopes, the number would approach a trillion galaxies, each one different, the larger ones containing billions, hundreds of billions, of stars, the most distant seen as it appeared billions of years in the past.

All—from our very selves, to our planets, to the nightly stars, to the Galaxy, to other galaxies—are locked together as part of the greatest of all structures, one that includes everything.

The Universe

In a kind of overwhelming simplicity, the Universe is "all there is." We have no idea how "big" it is, if that concept has any meaning at all. It might be infinite. However large, it has one great and singular characteristic: expansion. For nearly a century, we've known that the farther a galaxy is from us, the redder its light. The degree of this "redshift" is interpreted in terms of speed of recession: double the distance, double the velocity, and so on. It would seem that we are at some kind of center, with all the other galaxies madly fleeing from us. That view is an illusion. Since the velocities are in direct proportion to distance, every galaxy is moving away from every other galaxy. No matter in which one you might live, you would see the same thing.

At the same time, we cannot ignore the powerful effects of gravity. The expansion involves only large scales. The Earth is not expanding, and neither is the Galaxy; the mutual gravity of its components overwhelms any expansion effect. If galaxies are near each other, like ours and Andromeda, their mutual gravity is still strong enough to overcome the expansion, and keeps them together. Likewise, gravity maintains the integrity of even large clusters of galaxies. It is more accurate to say that isolated galaxies and clusters of galaxies are separating at velocities proportional to the distances between them.

The Universe then looks as if it has undergone some kind of gigantic explosion, with galaxies and their clusters hurling themselves through space. Another illusion. Einstein revealed an extraordinary depth to Nature, in which time and space are combined into a single four-dimensional entity called "spacetime." The apparent recession of galaxies is the result not of their movement through space, but of the expansion of spacetime itself. Galaxies, caught in its web, are merely going along for the ride.

The redshift is commonly misinterpreted as a "Doppler shift," which causes the light waves of a receding body to seem longer and thus redder, those of an approaching body to appear shorter and bluer. We hear the same thing in audio: an approaching car has a higher-pitched sound than a receding vehicle. Doppler shifts in the spectra of stars and other objects are critical to our understanding of them and of the Galaxy. What is really happening is that the photons from distant galaxies are stretched along with spacetime's expansion and therefore naturally lengthen, or "redden," during their long journeys to our eyes. The expansion rate gives the age since the beginning of the still-mysterious expansion. We—in the broadest sense—were born 13.7 billion years ago at a moment when all matter and energy were crushed into a "hot, dense state" whose actual origin is completely unknown. Our Sun and its planets, born from condensing dusty gases of interstellar space, came along 9 billion years later.

The evidence that the creation event, the "Big Bang," actually took place is deep and rich. Among the best is that the "fireball" from the Big Bang produced not only the mass of the Universe but—from the intense energy of its superheated state—a flood of short-wave, high-energy gamma rays. Just like the light from distant galaxies, over the past billions of years, they were stretched, becoming longer, that is, "redder." Another way of looking at it is that the heat of the original early Universe cooled such that it now contains only low-energy radio waves. We live in a constant bath of them called the Cosmic Microwave Background, whose radio photons surround us as if radiated from a body at a mere three Celsius degrees above the lowest possible temperature (absolute zero, –273 C), which is the value predicted by Big Bang theory. Ripples in this background represent the beginnings of assemblies of galaxies and also give us the same age as found from the galaxies' velocities. And nearly 14 billion years later, here we are, here are the stars, here are the planets, here are the heavens themselves.

Darkness

Yet for all our seeming knowledge, as did the stars of old, the Universe and its treasures remain shrouded in mystery. We have done a sort of inventory of the stores of energy and mass that it contains. The key to understanding lies in the Universe's "shape." Spacetime is rather like a four-dimensional sheet of rubber (however unimaginable that might be) that might be bent, distorted, even folded back upon itself in a variety of ways that depend critically upon the average amount of matter contained within a specified huge volume. Shape is crucial to know, as the calculated age of the Universe depends on it. The practitioners of the art of "cosmology," the study of the cosmos at large, can calculate the average,

Figure 1.5. The Hubble "Ultra-Deep Field" reveals thousands of galaxies within a pinhead of the sky a mere twentieth of a degree across, a tenth the angular size of the full Moon. A few big bright ones are relatively nearby, while the faintest stretch out to billions of light-years away. The farther they are, the faster they move away from us, the first clue that the Universe was created in a "Big Bang." Though their number seems overwhelming, galaxies such as these represent less than 1 percent of the mass-energy of the Universe. NASA, ESA, R. Windhorst (Arizona State University), H. Yan (Spitzer Science Center, Caltech).

smeared out, density of mass (including the mass equivalent of energy) that is required to roll out spacetime with no bends whatever, to make it, in a weird multidimensional way, "flat" (such that Euclid's famed plane geometry actually works).

Add up the stars and the stuff in the spaces between them, and it totals to just under a percent of that needed. More mass is indicated by Big Bang theory, which predicts how primitive hydrogen atoms combined to create a variety of light chemical elements. Much, if not most, of this matter seems to be in the form of hot gas that lies between the galaxies of large clusters, and even between clusters, where it is observed with X-ray telescopes. Some is matter left over from galaxy formation, while much was also ejected from the cluster's members by stellar explosions. Or so it's thought. Summarizing the various predictions and observations gets us close to 5 percent of the flatness requirement.

Then descends the shroud. Our Galaxy, its stars revolving around the center under the influence of their combined gravity, is spinning too fast for what we see. Galaxies in clusters orbit around the cluster's centers under the influence of *their* mutual gravities, but again, they move faster than expected. There must be something out there with enough of a gravitational hold to do the job, to speed things up, but it is completely unseen. *Dark matter*. It surrounds galaxies, pervades their clusters. We have no idea what constitutes it. Rather, there are *many* ideas, but none that can be proven. Add it all up based on the amount of mass needed to yield dark matter's gravity, and lo, one finds another 20 percent, getting us up (once the numbers are rounded off) to a quarter of that required to unfold the Universe, but still not enough.

To resolve the issue (and to add to the mystery at the same time), look deeper at the expansion. Modern telescopes, imagers, and above all, knowledge, have allowed cosmologists to measure the expansion rate to distances of billions of light-years, allowing us to look far back into time. We might expect a slowdown of the expansion as the combined gravity of everything in the Universe acts to hold it back. Velocity and redshift are indeed seen *not* to be quite in direct proportion to each other. Instead of showing a slowdown, the observed variance reveals the opposite, a surprising speedup! The expansion is getting ever faster. Any acceleration requires energy, which from its mass equivalent yields the missing 75 percent. Within the uncertainties of the data, the Universe is flat! But we have even less of an idea where this energy comes from than we do about the nature of dark matter. So to dark matter, add *dark energy*. Either that or something is terribly amiss with our concept of gravity.

We seem almost to be back to primitive times when we first looked up to the stars to wonder what they are. We are still wondering just as hard, perhaps not about stars as such, but about the stuff that surrounds them, which surely has a role in making them, and that then plays a role in making us. So we keep wondering and exploring. And as we reach out in our attempts to understand them all, from planets to galaxies, they in turn reach back to us to aid in our quest.

Heaven's Touch

Return to the outpost in deep space from which we observed the Milky Way. The scenery is quiet, serene, strikingly beautiful. Nothing seems to happen. Floating in the void we feel isolated, just as we would back on Earth where our own planet dominates us and our thoughts. What do these stars have do with us? We cannot reach them. Their great distances make it likely that no spaceship ever will. And there is no evidence that anyone out there—if there is anyone—has ever, or will ever, come here. All the connections we have with the distant cosmos seem to be from beautiful and benign starlight, which allows us to admire and study the Universe, but never to reach out and touch it.

Similar concepts of alienation extend to near space, to our Solar System. The Sun warms us with its light and heat, but otherwise we pay it little heed. One hundred million miles away—a hundred times the solar diameter, ten thousand times Earth's diameter—it seems otherwise not to affect or bother us. The Moon and planets, going through their once-mystifying movements (which we now fully understand from gravitational and orbital theory), are pleasing and fun to watch, but again they appear to have no direct bearing upon our own small world. Though we have gone to them, imaged them up close, have even landed upon them out of curiosity and a yearning for exploration, we could as easily have left them alone, as they do us.

Or do they? The story of discovery over the past century or more has starkly revealed that such isolationist views are the reverse of reality. Our senses are limited, and our life on Earth short compared with the flow of celestial time, both of which veil many of the remarkably varied ways in which the heavens directly interact with us. Indeed, life itself would be impossible without all these direct interactions.

Begin by standing at the beach to watch the water go up and down in synchrony with the position and phase of the Moon, all powered by gravity from a satellite a quarter million miles away, the cycle modified by the far more distant Sun. Not just for the watching, tides are a part of the fabric of life, perhaps even in part responsible for its creation. They—the tides—are on Earth, but not of Earth, as their production lies in the heavens, which reaches out to touch our world.

Through the tides, the Sun barely reveals its power. Northerners will tell you more, about the shining lights in the night sky, the northern lights that hang, that flow, that shoot luminous cannonballs across the sky, all caused by the pieces of atoms shot at us by the Sun, accelerated toward us in association with raging solar magnetism. Far more than causing pretty lights, solar storms disrupt our planet's magnetic field, make compasses go awry, break the electronics that ride aboard billion-dollar satellites, and can even make our lights go out. When the storms subside over long periods—decades—our Earth chills. Without the Sun's magnetic effects, it's even conceivable that terrestrial life could never have begun. More invisibly, billions of subatomic particles pass harmlessly through us each second from the deeply buried nuclear furnace that powers sunlight. The Sun, Helios, indeed reaches out to touch us in ways that we are only beginning to understand.

Move on to the planets, the Earth's brethren that orbit the Sun, from Mercury close in, to Uranus and Neptune far away, the Earth number three. All are satellites of the Sun that were created along with it some four and a half billion years ago. As does the Moon, they affect us through their gravity. Too far away to cause tides of any measurable sort, they instead act to pull on the whole Earth and alter its orbit. Over the aeons, the distance between the Earth and Sun changes first in one direction, then in the other, as does the orbital oblateness. Couple that with a 26,000-year wobble in our rotation axis caused by the Moon and Sun acting on an equatorial bulge that comes from terrestrial rotation, and our seasons and climate gradually change from variances in solar heating. Ice ages may be a consequence.

Benign though they may seem, the planets even come to visit, their attentions sometimes quite unwelcome. They were born through successive collisions of smaller bodies (built from dust grains) that orbited the primitive Sun. The process, however, was far from 100 percent efficient, resulting in a large amount of leftover debris that consists of the rocky-metallic small asteroids mostly between Mars and Jupiter and the icy comets that mostly reside beyond the planetary system. Acting as "dirty snowballs," cometary bodies measured in tens or hundreds of kilometers across lie in two great reservoirs. One, a flat but thick plate beyond Neptune, is made of comets that were too thinly spread to assemble into a planet. The other, holding comets that were kicked out of the planetary system by the giant outer planets, may extend halfway to the nearest star. If caught in a long, looping orbit, a comet can get close enough to the Sun so that its ices turn to gas, which, with the release of dust, produces the graceful tails iconic to astronomy.

Collisions among asteroids coupled with the gravitational effects of planets can toss these shredded bodies to the Earth. Hitting our atmosphere and heating, they first appear as streaks of light—meteors—crossing the sky. If large enough, they smack into us as meteorites to be visited in museums. The largest can dig giant craters in the ground, and in the most devastating of such events even wipe out whole species of life. Small rocks and dust grains flaked off comets produce a steady rain of such meteors, sometimes showers of them, sometimes whole storms of them to be admired. And comets can hit us too, with awesome force. Giant impacts on other planets can be so energetic as to launch rocks into orbit around the Sun, some of which eventually also hit us, giving us a cheap "space program," whereby we can take pieces of the Moon and Mars into our laboratories. Even stars can have such effects by gravitationally disturbing the outer icy cometary bodies, tossing them back toward us.

The Sun shines the same day after day. Inside is a highly controlled fusion machine that converts the solar hydrogen fuel into helium with the creation of energy. As the fuel runs out over long periods—billions of years—the Sun will gradually change. For a time, it will swell to swallow Mercury, perhaps Venus, perhaps in the ultimate solar effect even consuming Earth. It will then quietly shrink to a cooling dense ball comparable to our own planet's size. Other stars are not so lucky. Rare massive ones explode, whereupon they accelerate their surroundings outward at speeds close to that of light. The stuff rains down upon us as "cosmic rays" that manufacture the radioactive carbon that archaeologists use to date ancient ruins. Cosmic rays may even be the seeds that trigger lightning bolts, perhaps even some cloud formation, all from dying stars that are thousands of light-years away.

If near enough, the radiation from such explosions may be hazardous to life, indeed may even have caused one or more extinction events on Earth. Ordinary stellar explosions need stay at least 30 light-years away, while ultra-rare maximum detonations could damage us from thousands of light-years away. No wonder, since their effects can even be seen with the naked eye from *billions* of light-years' distance. The remains of these destroyed stars can be just as dangerous. Stellar blowups leave behind dense remnants that pack the mass of the Sun into balls no more than a few tens of kilometers across, into neutron stars that can have magnetic fields a million billion times stronger than Earth. Adjustments in these extreme stars and in their magnetic fields send out bursts of radiation so powerful that even though tens of thousands of light-years away, they can turn off orbiting satellites and disrupt communication.

In the ultimate connection, we came from out there. All the subatomic particles that make atoms and therefore ourselves were created in the Big Bang, the event that began our Universe. All the heavier chemical elements were made in aging and exploding stars, which also produced much of the energy needed to drive star and ultimately planet formation. We are not just *in* the cosmos, we are *of* the cosmos, we, along with all the other parts of it *are* the cosmos, all of it one, all of it allowing us to be born and to live our lives so as to understand and appreciate its grand beauty.

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